Time takes time to pass; considerations about neuro-motor development and early intervention

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Chapter 5:

DEVELOPMENT OF POSTURAL CONTROL IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN WITH CEREBRAL PALSY: POSSIBILITIES FOR INTERVENTION?[e]

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Chapter 5:

DEVELOPMENT OF POSTURAL CONTROL IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN WITH CEREBRAL PALSY: POSSIBILITIES FOR INTERVENTION?

Abstract

The basic level of postural control is functionally active from early infancy onwards: young infants possess a repertoire of direction-specific postural adjustments. Whether or not direction-specific adjustments are used depends on the child's age and the nature of the postural task. The second level of control emerges after 3 months: children start to develop the capacity to adapt postural activity to environmental constraints. But the adult form of postural adaptation first emerges after adolescence.

Children with cerebral palsy (CP) in general have the ability to generate direction-specific adjustments, but they show a delayed development in the capacity to recruit direction-specific adjustments in tasks with a mild postural challenge. Children with CP virtually always have difficulties in the adaptation of direction-specific activity.

The limited data available on the effect of intervention on postural development suggest that intervention involving active trial and error experience may accelerate postural development in typically developing infants and may improve postural control in children with or at high risk for a developmental motor disorder.

Introduction

Dysfunctional postural control is one of the key problems in children with cerebral palsy (CP), which interfere with the activities of daily life (Brogren et al. 2001, Van der Heide et al. 2004). However, little is known about the specific nature and development of the postural problems of children with CP. Such knowledge is needed for the development of successful therapeutic interventions and to evaluate efficacy of therapeutic interventions.

The current paper starts with a review of the development of postural control in typically developing children and in children with CP. The review zooms in on EMG-studies on muscle coordination during postural adjustments. Postural adjustments in children are assessed mainly with the help of two paradigms: 1) studies using the external perturbation paradigm in which postural adjustments are recorded during a sudden movement of the support surface of the sitting or standing child and 2) studies assessing internally triggered postural adjustments during reaching movements or locomotor activity.

In the second part of the paper we review current knowledge on the effect of intervention on muscle coordination during postural development in children with typical and atypical motor development.

Basic principals in the organization of postural adjustments

Postural control is organized to guarantee the maintenance of equilibrium and to keep the projection of the centre of mass (COM) within the stability limits of the body (Massion 1994). It involves the resistance to forces of gravity and mechanical support during movement (Massion 1998).

The current paper focuses on the balance maintaining aspect of postural control. For human beings keeping balance in vertical position is a motor control problem of reputed complexity: a multi-joint body has to be kept upright on a relatively small area of support with the help of many muscles. In terms of motor control, this means that the nervous system is faced with a problem of redundancy in degrees of freedom. Bernstein (1935) suggested that the adult nervous system solves this problem by creating motor synergies. This means amongst others that supraspinal control centres do not need to specify each single muscle contraction, but may use prestructured neural commands, i.e. the repertoire of synergies embedded in the spinal cord and brain stem.

Forssberg and Hirschfeld (1994) suggested that in the neural control of postural synergies two levels can be distinguished. The first level of control is involved in the generation of basic direction-specific adjustments. Direction-specificity means that perturbations inducing a forward sway of the body, such as reaching movements, are accompanied by postural activity in the muscles on the dorsal side of the body, whereas perturbations inducing a backward body sway are accompanied by activity in the ventral muscles (Forssberg and Hirschfeld, 1994). Functional activity at the second level of control means involvement in the fine-tuning of the basic postural pattern on the basis of multi-sensorial afferent input from somatosensory, visual, and vestibular systems. The modulation of postural adjustments can be achieved in various ways, for instance, by changing the number of direction-specific muscles recruited, by modifying the order in which the direction-specific muscles are recruited (*e.g.*, in a caudal-to-cranial sequence or in a reverse order, Hadders-Algra, 2005).

Developmental changes in the first level of control

Hedberg et al. (2004, 2005) suggested that the basic level of control of postural adjustments might have an innate origin. They evaluated postural muscle activity in response to sudden perturbations in sitting position in infants from 1 month onwards. The results revealed that at the age of 1 month, direction-specific activity was present in 85% of the trials requesting activity of the dorsal postural muscles and in 72% of the trials requiring activity of the ventral muscles (Hedberg et al. 2004). Between 2 and 4-5 months the rate of direction-specific adjustments remained 70-85% to increase to a virtually consistent presence in infants aged at least 7-8 months (Harbourne et al. 1993, Hadders-Algra et al. 1996, Hedberg et al. 2005).

The early development of internally trigged postural adjustments has been addressed in EMG-studies during reaching in supine and sitting conditions. ‘Pre-reaching’ movements in infants aged 1-3 months are accompanied by postural activity which in general lacks direction-specificity (Van der Fits et al. 1999a). At 3-4 months ‘pre-reaching’ activity is replaced by reaching movements towards an object and from 4-5 months reaching movements increasingly more often result in grasping of an object (Touwen 1976). At the age of 4 to 6 months about 50% of the reaches towards an object in supine and sitting position are accompanied by direction-specific activity in the dorsal postural muscles (De Graaf-Peters et al. 2007). This means that the presence of direction-specific postural activity is not a prerequisite for the generation of reaching movements, but it affects the ‘success’ of reaching movements. Reaching movements accompanied by direction specific adjustments end more often in successful touching or grasping of a toy than reaching movements accompanied by postural adjustments lacking direction-specificity. In the posturally more safe supine condition the success of reaching is independent of the presence of direction-specific activity (De Graaf-Peters et al 2007).

Van der Heide et al. (2003) showed that children from the age of 2 years onwards consistently use direction-specific adjustments while reaching in sitting position. This means that a consistent recruitment of direction-specific adjustments during reaching while sitting emerges at some age between 6 months and 2 years.

Until recently it was unclear whether direction-specific activity was present during stance in young infants who were not yet able to stand independently. Sveistrup and Woollacott (1996) had studied postural adjustments with the external perturbation paradigm in infants in the pull-to-stand phase during standing with support. The results indicated some, inconsistently present, direction-specific activity. It remained unclear, however, whether the absence of consistent direction-specific activity could be attributed to the infants' developmental level of neural control or to the presence of support, as it is well known that the presence of support alters postural activity (Cordo and Nashner, 1982). Recently, Hedberg et al. (2006) managed to study some infants at a similar developmental stage aged 8 to 10 months by means of external perturbations during stance *without* support. The data showed that direction-specific activity could be found consistently at least at one of the levels recorded, i.e. lower leg, upper leg and neck. But consistent direction-specificity at all levels recorded was first found at the age of 14 months, when all infants were able to stand independently. Previously it had already been demonstrated that young children who are well able to stand independently show consistent direction-specific postural activity during external perturbations in stance (Forssberg and Nashner 1982, Woollacott et al. 1987, Sveistrup and Woollacott 1996).

To summarize, already at young age, infants show direction-specific adjustments during lying supine and sitting. The extent to which direction-specific adjustments are found depends on the postural demands of the task. From the developmental age that infants can stand independently consistent direction-specific adjustments are found.

Developmental changes in the second level of control

Direction-specific postural muscle activity at young age is characterized by variation (Hadders-Algra 2005). Variation is found in muscles which are recruited, in the temporal ordering of muscle activity, in antagonist recruitment, and in the degree to which the postural muscles are contracted. However, within these variations, developmental trends can be distinguished.

Prior to the emergence of reaching, the development of postural muscle activity only has been studied by means of external perturbations in sitting infants. The external perturbation experiments revealed that infants at 1 month of age use a variable repertoire of direction-specific adjustments. This means that the direction-specific muscles are activated in any possible combination, including the so-called complete pattern during which all direction-specific muscles are activated in concert (Hedberg et al. 2004). At 1 month of age infants respond during 10-20 % of the perturbations with the complete pattern. But with increasing age the complete pattern is less often found, and around 3 months, this pattern is virtually absent. Prechtl (1984) already indicated that the age of 3 months may be considered as a moment of major neurodevelopmental transition. The finding that postural control untill the age of 3 months is not related to achievements in spontaneous motor behaviour in supine position whereas such a relation is present after

3 months, supports the notion of a transition (Hedberg et al. 2005, de Graaf-Peters et al. 2006). In addition, the Positron Emission Tomography studies of Chugani (1998) indicated that around the age of 3 months substantial changes occur in the distribution of metabolic activity in the brain. In newborn infants the highest degree of glucose metabolism, which might serve as an indicator of functional activity, is found in the primary sensory and motor cortex, cingulate cortex, thalamus, brain stem, cerebellar vermis, and hippocampal region. At 2 to 3 months of age glucose utilization increases in the parietal, temporal, and primary visual cortices, basal ganglia and cerebellar hemispheres.

After the age of 3-4 months the complete pattern more often occurs, but the muscle recruitment patterns still remain rather variable. The increase of the occurrence of the complete pattern has been reported for multiple conditions. For instance, at 6 months of age the occurrence of the complete pattern is already 50% during backward translations in sitting, 30% during forward translations and about 50% during reaching movements in supine and sitting position (Hadders-Algra et al. 1996a, De Graaf-Peters et al. 2007). After 6 months the use of the complete pattern further increases. At 9-10 months of age it is used in 75% of perturbation trials causing a backward sway of the body and in 100% of perturbation trials inducing forward body sway (Hadders-Algra et al. 1996a). A similarly high prevalence of the complete pattern during reaching in sitting position is first observed at 15 months of age (Hadders-Algra 2005). When the child becomes older the dominance of the complete pattern disappears. It disappears during reaching while sitting between the age of 18 months and 2 years and during external perturbations in sitting between 2½ and 3 years (Hadders-Algra et al. 1998, Van der Heide et al. 2003).

In stance, the development of muscle recruitment patterns only has been evaluated in studies using the external perturbation paradigm. Infants at the verge of independent stance show substantial variation in which direction-specific muscles are activated. The variation includes the complete pattern, which in the study of Hedberg et al. (2006) meant the activation of direction-specific lower- and upper leg muscles and neck muscles. A preference for the use of the complete pattern emerges at 2 years of age and lasts at least until the age of 10 years (Forssberg and Nasher 1982, Sveistrup and Woollacott 1996, Woollacott et al. 1998, Sundermier et al. 2001). It is even likely that the complete pattern remains the preference pattern into adulthood (Keshner et al. 1988, Aruin & Latash 1995).

The data indicate that the differences in ages at which the complete pattern is used preferentially in the various conditions, depend on differences in the nature of the postural task: an external perturbation challenges balance control more than a self-generated reaching movement and during standing and walking balance control is challenged more than during sitting.

Also the development of the recruitment order of the muscles involved in a postural adjustment is characterized by variation (Hadders-Algra et al. 1996a, De Graaf-Peters et al. 2007). Infants initially develop a slight preference for a top-down recruitment during which the neck muscle is recruited first (Hadders-Algra et al. 1996a, Van der Fits et al. 1999b, De Graaf-Peters et al. 2007). During reaching, the preference for top-down recruitment first becomes stronger between 4 and 6 months (De Graaf-Peters et al. 2007). But infants of 8 to10 months who sit independently have a slight preference for a bottom-up recruitment (Hadders-Algra et al. 1996a, Van der Fits et al. 1999b). From preschool age onwards recruitment order during external perturbations and reaching in sitting is characterized by variation (Hadders-Algra et al. 1998, Brogren et al 1998, Van der Heide et al. 2003). During reaching a gradual preference within the variation develops for top-down recruitment. But it is only after puberty that the top-down recruitment becomes the dominant recruitment order during reaching (Van der Heide et al. 2003).

During the initial phases of standing, postural adjustments are also characterized by variation in recruitment order. However, the perturbation experiments showed that a preference for a bottom-up strategy emerges already between 10 and 12 months (Hedberg et al. 2006). The preference for bottom-up recruitment order persists into adult life, in particular during external perturbations (Nashner 1976, Nashner et al. 1979, Forssberg & Nasher 1982, Sveistrup and Woollacott 1996, Woollacott et al. 1998, Sundermier et al. 2001). In this respect it is interesting to note that adults during self-produced arm movements show a considerable variation in recruitment order (Cordo & Nashner 1982, Aruin and Latash 1995).

The data above indicate that the capacity to fine-tune postural activity to task constraints in terms of recruitment order emerges between 4 and 6 months of age. In addition they underline that recruitment order during childhood is characterized by variation. Whether or not a child adopts a preference for a specific form of recruitment depends in particular on the child’s age and the nature of the postural challenge.

Remarkably, the development of postural adjustments in sitting position is characterized by the absence of antagonistic co-activity (Hadders-Algra et al. 1996, Van der Fits et al. 1999a, Hedberg et al. 2005). Only between 6 and 24 months some antagonistic activity is observed in specific situations: during external perturbations inducing a backward sway of the body

(Hadders-Algra et al. 1996a, 1998) and in the neck muscles during reaching (Van der Heide et al. 2003).

During the development of standing the situation is different. Perturbation experiments indicated that during the earliest phases of stance development some antagonistic activity may be observed (Sveistrup and Woollacott 1996, Hedberg et al. 2006). Children aged 1½ -5 years often exhibit antagonistic co-activation in the leg muscles when balance is disturbed by an external force (Forssberg and Nashner 1982, Berger et al. 1992, 1995). Beyond the age of about 5 years the antagonistic muscles no longer are co-activated with the agonist, but they are recruited in a reciprocal manner (Forssberg and Nashner 1982, Sundermier et al. 2001). Antagonistic co-activation may be found beyond the age of 5 years, but only in situations during which balance is threatened considerably, e.g. during rapid backward displacements: adult subjects show in this situation a co-activation of the lower leg muscles (Nashner en Cordo 1981, Oddsson 1989).

Amplitude modulation of EMG activity is considered to be one of the most subtle forms of fine tuning of postural control (Van de Heide et al. 2003). The ability to modulate postural adjustments in this subtle way emerges at 9-10 months. From that age infants are able to adapt postural muscle activity with respect to the velocity of a reaching arm movement and to the amount of forward or backward rotation of the pelvis in sitting position (Hadders-Algra et al. 1996a, Van der Fits et al. 1999). Which muscle's activity is modulated strongly depends on the nature of the task. For instance, sitting children aged 3 to 7 years in particularly modulate the amplitude of the upper leg muscles during external perturbations inducing a backward body-sway (Brogren et al 2001). During reaching while sitting preschool and school-aged children do not show a clear preference to modulate the degree of contraction of a specific direction specific muscle. It is only after puberty that a preference to modulate the amplitude of the more cranially located muscles emerges (Van der Heide et al. 2003).

Perturbation experiments during standing revealed that from the age of independent stance children are able to modulate EMG amplitude with respect to the size of the perturbation (Roncesvalles et al. 2002). Like in the sitting position, the way in which the degree of contraction of the direction-specific muscles is modulated strongly depends on the nature of the postural task and the age of the child. Berger et al. (1992, 1995) showed that in the age period between 2 and 11 years the degree to which lower leg muscle EMG amplitude is modulated during external perturbations decreases with increasing age. They also reported that the activity of the direction-specific tibialis anterior was modulated to a larger extent than that of the direction-specific gastrocnemius muscle.

Summarizing, the development of the second level of control is complex and is characterized by variation. The developmental timing of the various aspects of the fine tuning of postural control depends on the difficulty of the postural task. The fine tuning of postural control runs a protracted course: it first reaches an adult level of control after adolescence.

Postural control in children with CP

Nowadays CP is described as ‘a group of disorders of the development of movement and posture, causing limitation in activity, that are attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder’ (Bax et al. 2005). The definition underscores the notion that there is large variation amongst children diagnosed with CP. Children with CP invariably show deficits in development of postural control. The exact nature of the deficits is only known to a limited extent. Most studies on postural muscle activity in children with CP assessed relatively small groups of children, dealt with school-age only, and only included children with mild to moderate forms of the disorder. Current knowledge is outlined below.

Only one study addressed the development of postural control of children with CP during infancy (Hadders-Algra et al. 1999). The study consisted of a longitudinal assessment of postural control during reaching between 4 and 18 months in five infants with a spastic hemiplegia and two infants with severe bilateral spastic CP. The infants with spastic hemiplegia showed direction-specific adjustments from 15 months onwards. Unlike typically developing infants they did not develop the ability to modulate EMG-amplitude to the velocity of the reaching arm or to initial pelvis position in the age period till 18 months. Postural development of one of the infants with bilateral spastic CP resembled that of the infants with hemiplegia, but it proceeded at a slower pace. Postural control of the other infant with bilateral spastic CP, who also showed signs of dyskinesia and who was not able to sit at the age of 4 years, was severely disorganised: she lacked direction-specific postural adjustments and was not able to adjust postural activity to task-specific conditions.

Also beyond infancy children with CP in general show direction-specific postural activity, both during sitting and standing (Nashner et al. 1983, Burtner et al. 1998, Woollacott 1998, Brogren et al. 1998, 2001, Van der Heide et al. 2004). However, mild to moderate problems to recruit direction-specific activity may occur in particular in the leg muscles (Van der Heide et al. 2004, Woollacott et al. 2005). Only children with severe CP not able to sit independently show a total lack of direction specific postural adjustments

(Hadders-Algra et al. 1999a,b). Preschool and school-age children with cerebral palsy always show dysfunctions in the fine tuning of the postural adjustment, i.e. an invariable recruitment order, an excessive degree of antagonistic co-activation during external perturbations, and a reduced capacity to modulate postural adjustments (Van der Heide et al. 2004, Brogren Carlberg and Hadders-Algra 2005).

A strong preference for a top-down recruitment of the postural muscles in children with CP is found, not only during perturbation experiments in sitting and standing position, but also during reaching in a sitting position (Nashner et al. 1983, Brogren et al. 1998, Woollacott et al. 1998, Van der Heide et al. 2004). A clear cranio-caudal recruitment involves an early recruitment of the neck extensor muscle. The fact that this strategy more often occurs in children with mild to moderate forms of CP than in children with severe CP, might indicate that the preference for cranio-caudal recruitment reflects the child's strategy to cope with deficient postural control (Latash and Anson 1996, Van der Heide et al. 2004). In addition, the top-down recruitment strategy might reflect that head stabilization in space is a major goal of postural control (Pozzo et al. 1990).

Children with CP show a high amount of antagonistic co-activation during perturbation experiments in sitting and standing position (Brogren et al. 1998; 2001, Woollacott et al. 1998, Woollacott and Shumway-Cook 2005). In sitting position co-activation is especially high during perturbations inducing a backward body sway (Brogren et al. 1998, 2001). During perturbations inducing a forward sway of the body little antagonistic co-activation is found. This could be related to a higher stability in this situation induced by the configuration of the sitting body and to more experience as forward body sway is frequently used in daily activities such as reaching (Brogren et al. 1998; 2001). Antagonistic co-activation is rarely found in children with CP during reaching in a sitting position (Van der Heide et al. 2004).

The major postural dysfunction of children with CP is the substantially reduced capacity to modulate the degree of postural muscle contraction to the specifics of the situation (Brogren et al. 2001, Van der Heide et al. 2004, Woollacott et al. 2005). Children with CP have for instance difficulties in using information stemming from the initial body configuration to adapt postural activity during reaching while sitting (Van der Heide et al. 2004). Children with spastic hemiplegia are able to use the information of the body configuration to some extent to modulate postural activity during reaching; children with bilateral spastic CP lack this capacity entirely (Van der Heide et al. 2004). Children with CP are able to use the information originating from the reaching arm, including the velocity of the arm to adjust the degree of contraction of the direction-specific postural muscles (Van der Heide et al. 2004).

The above data indicate that children with severe forms of CP, i.e. children who are not able to sit independently by the age of 1½ years, are hampered by serious dysfunction of the basic level of postural control. In children with less severe forms of CP the first level of control is basically intact. At the second level of control, multiple forms of disorganization and/or adaptation are found: a dominance of cranio-caudal recruitment, an increased degree of antagonistic co-activation and a reduced or absent capacity to adapt the degree of muscle contraction to the specifics of the situation. The extent to which these problems are present depends on the postural challenge of the situation.

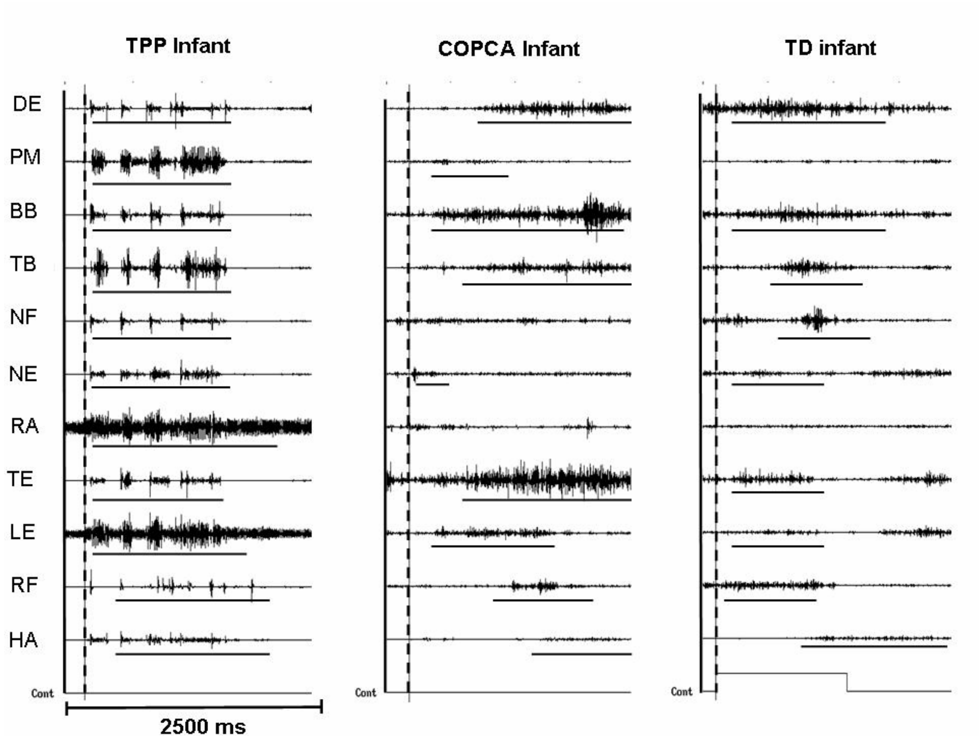

Figure 1

Effect of two types of intervention in infants at high risk for developmental motor disorders on postural control. Typical examples of postural activity during reaching in sitting position at 6 months in an infant who had received traditional paediatric physiotherapy (TPP; left panel), an infant who had received COPCA intervention (middle) and a typically developing (TD) infant (right panel). Duration of each trial is 2500 ms. DE = Deltoid, PM = Pectoralis Major, BB = Biceps brachii, TB = Triceps brachii, NF = neck flexor, NE = neck extensor, RA = rectus abdominis, TE = thoracal extensor, LE = lumbar extensor, RF = rectus femoris, HAM = hamstrings. Dotted vertical lines denote the onset of the reaching movement as indicated by simultaneously recorded kinematics. Horizontal lines delineate the presence (onset and offset) of significant EMG bursts as defined by the computer algorithm. During the reaching movement of the TD infant (right) postural activity in neck and trunk is direction-specific: NE starts prior to NF; TE and LE are recruited, the antagonistic RA not. Postural activity in the infants who received COPCA and TPP intervention is also direction-specific. However note the synchronous recruitment of the postural muscles shortly after the onset of reaching in the infant of the TPP group.

The effect of intervention on development of postural control

Paediatric physiotherapeutic intervention in children with or at high risk for developmental motor disorders often aims at improving postural control. However, only limited information is available on the effect of intervention on postural muscle activity.

Two studies addressed the effect of training on the development of postural control in typically developing infants. Hadders-Algra et al. (1996) studied the effects of balance training on postural control in sitting during infancy. At the age of 5-6 months 20 infants were randomly assigned to a group which obtained three months of daily balance training or a control group without balance training. Balance training was carried out at home by family members and consisted of playful presentation of toys in the sideward and semi-backward direction in the border zone of sitting without falling. The balance play was carried out three times a day during 5 minutes. Postural control was assessed by means of external perturbations in sitting position at base-line, at the age of 7-8 months and once again at 9-10 months. The data revealed a significant effect of training on the organization of postural activity at the second level of control: the trained infants showed a clearly accelerated development of the ability to select the complete pattern out of their repertoire and of the ability to modulate the degree of ventral muscle contraction to the velocity of the moving platform and to body configuration at perturbation onset. The other study was carried out by Sveistrup and Woollacott (1997). They studied the effect of exposure to 100 balance perturbations per day during three consecutive days in 15 infants in the pull-to-stand phase aged 9-11 months. The study indicated that training resulted in an increase of the rate of direction-specific adjustments, an increase of the use of the complete pattern, and of distal to proximal muscle recruitment. This means that balance training in typically developing infants may result in an acceleration of postural development.

One study addressed the effect of balance training in children with CP (Shumway-Cook et al. 2003, Woollacott et al. 2005). Woollacott and coworkers trained balance in four children with bilateral spastic CP and two children with spastic hemiplegia aged 7 to 13 years by means of exposure to 100 balance perturbations per day for a period of five days. The training resulted in improvements in the direction-specificity of the adjustments, a faster recruitment of the postural muscles, a more frequent use of a bottom-up recruitment and an improved ability to modulate the degree of muscle contraction (Woollacoot et al. 2005). The improvements in postural muscle activity were associated with a reduction of postural sway (Shumway-Cook et al. 2003).

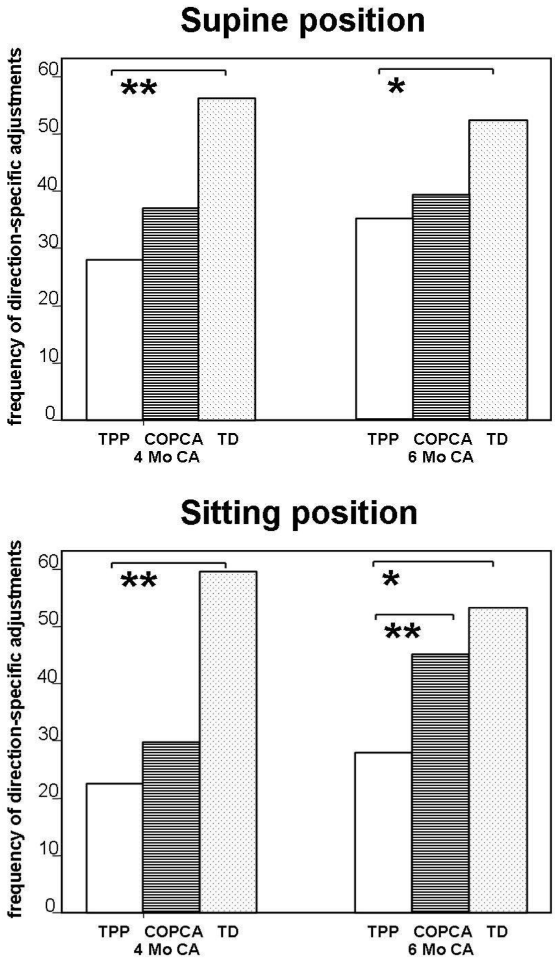

Figure 2

Effect of two types of intervention in infants at high risk for developmental motor disorders on frequency of direction-specific adjustments at 4 and 6 months in supine and sitting position, including reference values of age-matched typically developing (TD) infants (n=12). The boxes represent median values. TPP = group which received traditional paediatric physiotherapy (n=11), COPCA = group which received COPCA intervention (n=9). Mann Whitney: ** $p \leq 0.01$, * $p < 0.05$. Not indicated with a symbol: significant increase in direction-specificity in sitting COPCA infants between 4 and 6 months (Wilcoxon $p = 0.04$)

Recently we evaluated the effect of two forms of early intervention on postural development in 20 infants at high risk for developmental motor disorders such as CP. Infants with definitely abnormal general movements at the corrected age of 3 months were randomly assigned to either traditional paediatric physiotherapeutic intervention (n=11) or a novel intervention program called COPCA (n=9). COPCA (Coping and caring for infants with neurological dysfunction – a family centred programme; see Blauw-Hospers et al. 2007, this issue) is based on the motor developmental principles of the Neuronal Group Selection Theory (NGST; Edelman 1989, Hadders-Algra 2000a,b) and on new insights in the field of education and family care (Dale 1996, Rosenbaum et al. 1998). Traditional paediatric physiotherapy in the Netherlands usually consists of NeuroDevelopmental Treatment (NDT). Intervention was provided for a period of three months. Postural activity was assessed at 4 and 6 months during reaching while lying supine and while sitting with support. At the age of 4 months both groups of at risk infants showed less direction-specific activity in supine and sitting than age-matched typically developing infants. At the age of 6 months postural control in the group of infants who had received COPCA intervention was in some aspects significantly better than that of the group who had received traditional paediatric physiotherapy (Figures 1-4). The infants who had received COPCA intervention showed more direction-specific adjustments in sitting (Figure 2), more often recruited the complete pattern in supine and sitting position (Figure 3) and showed significantly less often a synchronous onset of postural muscle activity (Figures 1 and 4). Postural performance at 6 months of the high risk infants who had received COPCA intervention had improved to such an extent that it closely resembled that of typically developing peers.

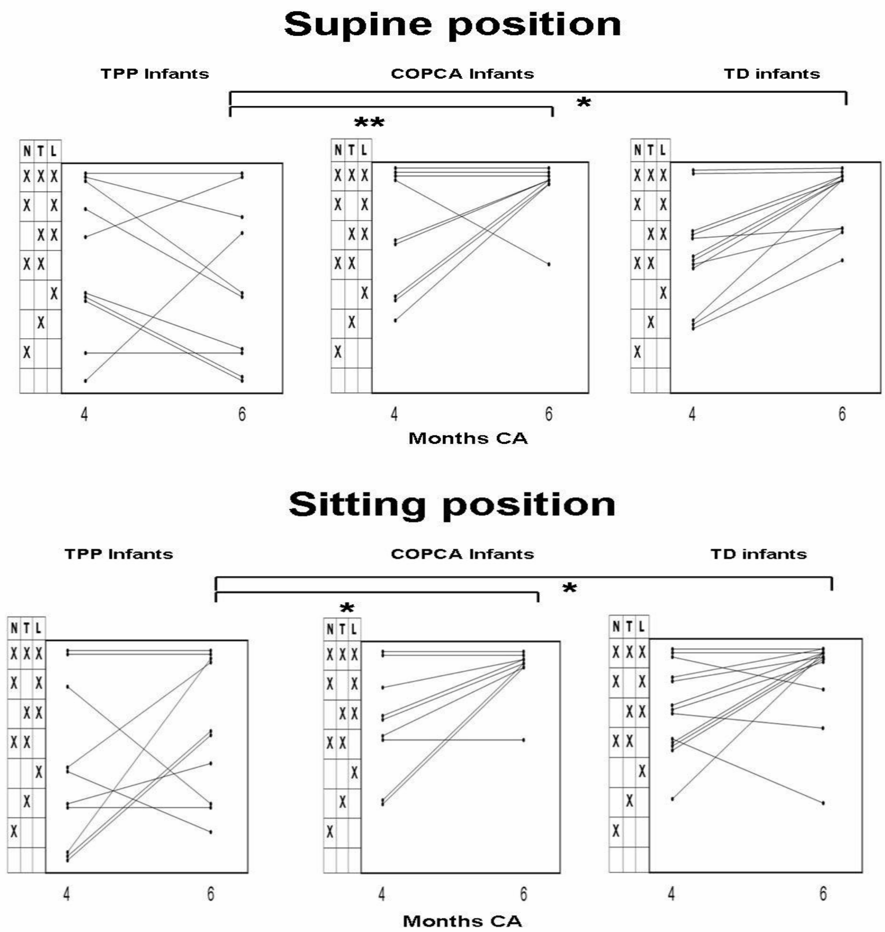

Figure 3

Effect of two types of intervention in infants at high risk for developmental motor disorders on individual developmental trajectories of preference patterns between 4 and 6 months, including reference data of age-matched typically developing (TD) infants (n=12). TPP = group which received traditional paediatric physiotherapy (n=11), COPCA = group which received COPCA intervention (n=9). The preference pattern is defined as the pattern present in at least 50% of the trials. Each line represents the development of one infant. N= Neck extensor, T = Thoracal extensor, L= Lumbar extensor. **X** indicates participation of a direction-specific muscle in a pattern. Three X's represent the complete pattern**.** Differences in the preference of the complete pattern at 6 months between the various groups: Mann Whitney: ** $p \leq 0.01$, * $p < 0.05$.

The two studies on the effect of intervention on postural development in children with or at risk for a developmental motor disorder indicate that intervention which requires active trial and self-produced and variation error experience is able to improve postural control. The data also suggest that the more traditional approach of intervention, such as NDT, which involves a substantial amount of handling and provision of postural support, is not effective in improving postural development.

Concluding remarks

During typical development the basic level of postural control is functionally active from early infancy onwards. This means that already at early postnatal age the infant possesses a repertoire of direction-specific postural adjustments. Whether or not direction-specific adjustments are used depends on the child's age and the nature of the postural task. After the age of major neurodevelopmental transition at 3 months the capacity to adapt postural activity to environmental constraints emerges. Yet, it takes at least till adolescence before an adult type of postural adaptation has been achieved.

Children with CP in general have the ability to generate direction-specific adjustments, but they show a delayed development in the capacity to recruit direction-specific adjustments in tasks with a mild postural challenge, such as reaching while sitting. Children with CP virtually always have difficulties in the fine-tuning of postural activity.

The few studies available on the effect of intervention on postural development indicate the following. Intervention by means of balance training accelerates the development of postural control in typically developing infants. There is also some evidence that balance training with active trial and error experience may improve postural control in children with or at high risk for a developmental motor disorder. Intervention by means of NDT does not result in improved postural control.

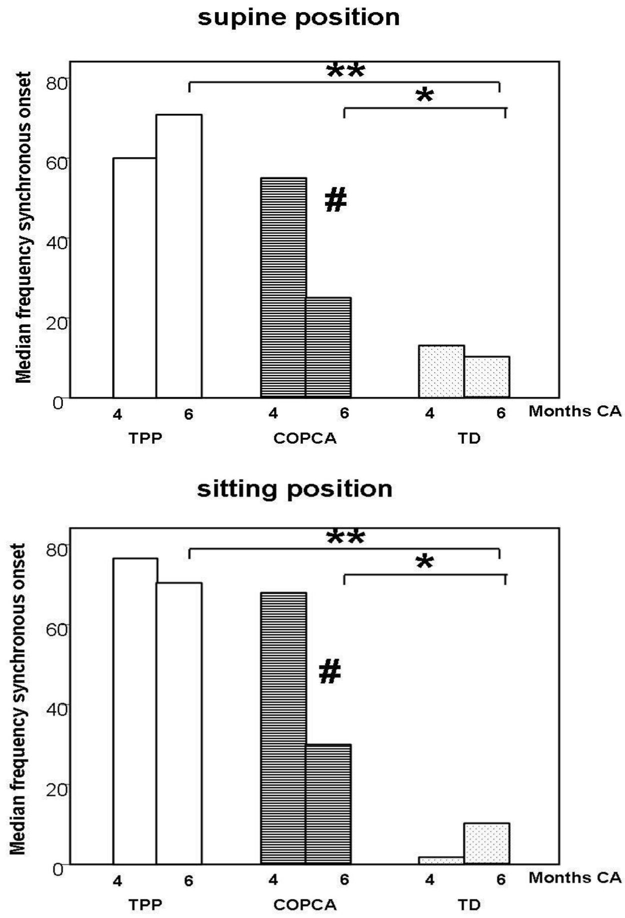

Figure 4

Effect of two types of intervention in infants at high risk for developmental motor disorders on postural control on the frequency of synchronous postural muscle activity at 4 and 6 months in supine and sitting position, including reference data of age-matched typically developing (TD) infants (n=12). TPP = group which received traditional paediatric physiotherapy (n=11), COPCA = group which received COPCA intervention (n=9). Synchronous postural muscle activity was defined as present when at least two of the five neck and trunk muscles had been recruited in the narrow time-window ending at 80 ms after the onset of the prime mover, i.e. the arm muscle recruited first. The boxes represent median values. Between group differences: Mann Whitney: ** $p \leq 0.01$, * $p < 0.05$. Within group differences: Wilcoxon: **#** $p < 0.01$. Differences between TD group and intervention groups at 4 months not indicated with symbols: Mann Whitney: TPP-supine: p = 0.001, TPP-sitting: p = 0.04, COPCA-supine: p = 0.002, COPCA-sitting: p = 0.001.

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References

1) Aruin, A.S., Latash, M.L., 1995. The role of motor action in anticipatory postural adjustments studied with self-induced and externally triggered perturbations. Exp Brain Res, 106: 291-300

2) Bax, M., Goldstein, M., Rosenbaum, P., Leviton, A., Paneth, N., Dan, B., Jacobsson, B., Damiano, D., 2005. Executive Committee for the Definition of Cerebral Palsy. Proposed definition and classification of cerebral palsy, Dev Med Child Neurol., 47: 571-6

3) Berger, W., Discher, M., Trippel, M., Ibrahim, I.K., Dietz, V., 1992. Developmental aspects of stance regulation, compensation and adaptation, Exp Brain Res, 90:610-619

4) Berger, W., Trippel , M., Assaiante, C.; Zijlstra, W.; Dietz, V., 1995. Developmental aspects of equilibrium control during stance: a kinematic and EMG study. Gait and Posture, 3: 149-155

5) Bernstein, N., 1935. The problem of the interrelation of coordination and localisation. Arch Biol Sci, 38: 15–59. Reprinted in: Bernstein, N., The coordination and regulation of movements, 1967, Pergamon Press, Oxford

6) Blauw-Hospers, CH., de Graaf-Peters, VB., Dirks, T., Bos, AF., Hadders-Algra, M. 2007. Indications that early intervention in infants

at high risk for a developmental motor disorder may improve motor and cognitive development. Neurosci Biobehav Rev, same issue.

7) Brogren Carlberg, E., Hadders-Algra, M., 2005. Postural dysfunction in children with cerebral palsy: some implications for management. Neural Plast, 12: 149-158.

8) Brogren, E., Hadders-Algra, M., Forssberg, H., 1998. Postural control in sitting children with cerebral palsy. Neurosci Biobehav Rev, 22: 591–596.

9) Brogren, E., Forssberg, H., & Hadders-Algra, M., 2001. Influence of two different sitting positions on postural adjustments in children with spastic diplegia. Dev.Med.Child Neurol., 43: 534-546

10) Burtner, P.A., Qualls C., Woollacott, M.H., 1998. Muscle activation characteristics of stance balance control in children with spastic cerebral palsy. Gait Posture, 8:163-174

11) Chugani, H.T. (1998). A critical period of brain development: Studies of cerebral glucose utilization with PET. Preventive Medicine, 27, 184-188.

12) Cordo, P.J., Nashner, L.M ., 1982. Properties of postural adjustments associated with rapid arm movements. J Neurophysiol., 47: 287-302.

13) Dale N., 1996. Working with families of children with Special Needs. Routledge London.

14) De Graaf-Peters, V.B., De Groot-Hornstra, A.H., Dirks, T., Hadders-Algra, M., 2006. Specific postural support promotes variation in motor behaviour of infants with minor neurological dysfunction. Dev.Med.Child Neurol., 48: 966-72

15) De Graaf-Peters, V.B., Bakker, J., Van Eykern, L.A., Otten, E., Hadders-Algra, M., 2007. Postural adjustments and reaching in 4- and 6-months-old infants: an EMG and kinematical study. Exp Brain Res. 2007 May 16; DOI 10.1007/s00221-007-0964-6

16) Edelman, G.M., 1989. Neural Darwinism. The Theory of Neuronal Group Selection. Oxford, Oxford University Press.

17) Forssberg, H., Nashner, L.M., 1982. Ontogenetic development of postural control in man: Adaptation to altered support and visual conditions during stance. J Neurosci., 2: 545-552

18) Forssberg, H., Hirschfeld, H., 1994. Postural adjustments in sitting humans following external perturbations: muscle activity and kinematics. Exp Brain Res, 97: 515–527

19) Hadders-Algra, M., 2000a. The neuronal group selection theory: a framework to explain variation in normal motor development. Dev Med Child Neurol, 42: 566-572

20) Hadders-Algra, M., 2000b. The neuronal group selection theory: promising principles for understanding and treating developmental motor disorders. Dev Med Child Neurol, 42: 707-715
21) Hadders-Algra, M., 2005. Development of postural control during the first 18 months of life. Neural Plast, 12: 99-108
22) Hadders-Algra, M., Brogren, E., Forssberg, H., 1996. Training affects the development of postural adjustments in sitting infants. J Physiol, 493: 289- 298
23) Hadders-Algra, M., Brogren, E., Forssberg, H., 1998. Postural adjustments during sitting at pre-school age: presence of a transient toddling phase. Dev Med Child Neurol, 40: 436– 47
24) Hadders-Algra, M., Van der Fits, I.B.M., Stremmelaar, EF., Touwen, BCL., 1999a. Development of postural adjustments during reaching in infants with cerebral palsy. Dev. Med. Child Neurol, 41: 766–76.
25) Hadders-Algra, M., Brogren, E., Katz-Salamon, M., Forssberg, H., 1999b. Periventricular leukomalacia and preterm birth have a detrimental effect on postural adjustments. Brain, 1999b, 122: 727–40.
26) Harbourne, R.T., Giuliani, C., MacNeela,, J., 1993. A kinematic and electromyographic analysis of the development of sitting posture in infants. Dev Psychobiol, 26: 51–64.

27) Hedberg, Å., Forssberg, H., Hadders-Algra, M., 2004.Early development of postural adjustments in sitting position: evidence for the innate origin of direction specificity. Exp Brain Res, 157: 10-17
28) Hedberg, Å., Brogren-Carlberg, E., Forssberg, H., Hadders-Algra, M., 2005. Development of postural adjustments in sitting position during the first half year of life. Dev Med Child Neurol, 47: 312-320
29) Hedberg, Å., Schmitz, C., Forssberg, H., Hadders-Algra, M., 2006. Early development of postural adjustments in standing with and without support. Exp Brain Res, Nov 9; Epub ahead of print
30) Keshner, E.A., Woollacott, M.H., Debu, B., 1988. Neck, trunk and limb muscle responses during postural perturbations in humans. Exp Brain Res, 71: 455-466
31) Latash, M.L., Anson, J.G., 1996. What are “normal movements” in atypical populations? Behav Brain Sci, 19: 55–68.
32) Massion, J., 1994. Postural control system. Current Opinion Neurobiol, 4: 877–887.
33) Massion, J., 1998. Postural control systems in developmental perspective. Neurosci Biobehav Rev, 22: 465–472
34) Nashner, L. M., 1976. Adopting reflexes controlling the human posture. Exp. Brain Res. 26: 59-72.

35) Nashner, L.M., Cordo, P.J., 1981. Relation of postural responses and reaction-time voluntary movements in human leg muscles. Exp Brain Res. 43: 395-405.

36) Nashner, L. M., Woollacott, M., Tuma, G., 1979. Organization of rapid response to postural and locomotor-like perturbations of standing man. Exp Brain Res. 36: 463-476.

37) Nashner, L.M., Shumway-Cook, A., Marin, O., 1983. Stance posture control in select groups of children with cerebral palsy: deficits in sensory organization and muscular coordination. Exp Brain Res, 49: 393–409.

38) Oddsson, L., 1989. Motor patterns of a fast voluntary postural task in man: trunk extension in standing. Acta Physiol Scand. 136: 47-58

39) Pozzo, T., Berthoz, A., Lefort, L., 1990. Head stabilisation during various locomotor tasks in humans. I. Normal subjects. Exp Brain Res, 82: 97–106.

40) Prechtl, H.F.R., 1984. Continuity of neural functions from prenatal to postnatal life. Clin. Dev. Med, 94, Oxford: Blackwell Scientific Publications.

41) Roncesvalles, M.N., Woollacott, M.H., Brown, N., Jensen, J.L., 2004. An emerging postural response: is control of the hip possible in the newly walking child? J Mot Behav, 36: 147-159

42) Rosenbaum P., King S., Law M., King G., Evans J., 1998. Family centered service: a conceptual framework and research review. Phys Occup Ther Pediatr, 18: 1-20.

43) Shumway-Cook, A., Hutchinson, S., Kartin, D., Price, R., Woollacott, M., 2003. Effect of balance training on recovery of stability in children with cerebral palsy, Dev Med Child Neurol, 45: 591–602.

44) Sundermier, L., Woollacott, M., Roncesvalles, N., Jensen, J., 2001. The development of balance control in children: comparisons of EMG and kinetic variables and chronological and developmental groupings. Exp Brain Res, 136: 340–350.

45) Sveistrup, H., Woollacott, M., 1996. A longitudinal study of the development of postural control in infants. Journ Mot Behav, 28: 58–70

46) Sveistrup, H., Woollacott, M., 1997. Practice modifies the developing automatic postural response? Exp Brain Res, 114: 33–43.

47) Touwen, B., 1976. Neurological development in infancy. Clin Dev Med No. 58. London: Heinemann Medical Publications.

48) Van der Fits, I.B.M., Klip, A.W.J., van Eykern, L.A., Hadders-Algra, M., 1999a. Postural adjustments during spontaneous and goal

directed arm movement in the first half year of life. Behav Brain Res, 106: 75–90.

49) Van der Fits, I.B.M., Otten, E., Klip, A.W.J., Van Eykern, L.A., Hadders-Algra, M., 1999b. The development of postural adjustments during reaching in 6–18-month-old infants: evidence for two transitions. Exp Brain Res, 126: 517–528

50) Van der Fits, I.B.M., Flikweert, E.R., Stremmelaa,r E.F., Martijn, A., Hadders- Algra, M., 1999c. Development of postural adjustments during reaching in preterm infants. Pediatr Res, 46: 1–7.

51) Van der Heide, J.C., Otten, E., van Eykern, L.A., Hadders-Algra, M., 2003. Development of postural adjustments during reaching in sitting children. Exp Brain Res, 151: 32–45.

52) Van der Heide, J.C., Begeer, C., Fock, A., Otten, B., Stremmelaar, E.F., van Eykern, L.A., Hadders-Algra, M., 2004. Postural control during reaching in preterm children with cerebral palsy. Dev Med Child Neurol, 46: 253-66

53) Woollacott, M., Debû, B., Mowatt, M., 1987. Neuromuscular control of posture in the infant and child: is vision dominant? J Mot Behav, 19: 167–186

54) Woollacott, M., Burtner, P., Jensen, J., Jasiewicz, J., Roncesvalles, N., Sveistrup, H., 1998. Development of postural responses during

standing in healthy children and in children with spastic diplegia. Neurosci Biobehav Rev, 22: 583–589.

55) Woollacott, M., Shumway-Cook, A., Hutchinson, S., Ciol, M., Price, R., Kartin, K., 2005. Effect of balance training on muscle activity used in recovery of stability in children with cerebral palsy: a pilot study. Dev Med Child Neurol, 47: 455–461